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ANNUAL REPORT OF THE DIRECTOR OF THE MOUNT WILSON SOLAR OBSERVATORY

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[Extracted from Year Book No. 16, for the year 1917, pp. 199 to 235.]

MOUNT WILSON SOLAR OBSERVATORY.*

George E. Hale, Director.

INTRODUCTORY SKETCH OF THE YEAR'S WORK.

The far-reaching influences of the war, so disastrous in their effect upon the progress of science in Europe, are clearly reflected in the Observatory's history for the past year. The resulting diminution in research activity, however, has not been serious. The Director has been called upon to devote nearly all of his time to the organization and work of the National Research Council, which since February has served as the Department of Science and Research of the Council of National Defense. Fortunately he was able to leave the Observatory's work in the hands of the Assistant Director, who deserves full credit for its successful conduct during the greater part of the year.

The prolonged activity of the sun, hardly yet at its maximum, has afforded excellent opportunity for a variety of work. Sun-spots are so numerous that an average of nearly 40 (including the members of groups) have been observed daily for magnetic phenomena, while other evidences of solar unrest have been on a corresponding scale. The successful continuation of laboratory researches on the Stark effect has provided means for another test of the presence of free electricity in sun-spots, but the outcome, as in previous years, has been negative. Thus, while we can hardly doubt that the intense magnetic fields in sun-spots are due to electrically charged particles whirling in vortices, the full explanation of the effect is yet to be developed. The same may be said of the nature of the spot vortex. The association in pairs of sun-spots of opposite magnetic polarity remains a phenomenon of almost unbroken occurrence and undoubted significance. But the simple hypothesis that the two members (single or multiple) of the group represent the extremities of a half-ring vortex, while fruitful as a guide to research, can hardly be taken at its face value, in view of the complex polarity phenomena presented by large and active spot-groups; so long as this hypothesis remains useful in suggesting new lines of work, however, it will not be wholly discarded.

The sudden reversal of magnetic polarity exhibited by sun-spots at the last minimum of solar activity (1912) has given no sign of repetition since that date. If the maximum is to be accompanied by a reversion to the former state, the effect should soon appear. Meanwhile we may speculate sparingly on the meaning of this unexpected change of polarity. If, as we suppose, the magnetic fields in spots are due to the whirl of charged particles in vortices, the direction of the rotary motion in the preceding (and following) spots of bipolar groups is now opposite to its direction during the years 1908 to 1912. Thus it is as if the cyclones and tornadoes north of the earth's equator were suddenly to whirl clockwise instead of counter-clockwise—an event impossible without profound changes in atmospheric circulation.

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*Situated on Mount Wilson, California. Address, Pasadena, California.

In the sun, as the last report pointed out, the rotary motion of the hydrogen vortices of the upper atmosphere showed no reversal of sign at the sun-spot minimum. This stability presumably indicates that their direction of whirl is determined, not by the action of the magnetic fields below them, but mainly by the conditions existing in the higher atmosphere, where marked variations in solar activity have been shown to be unaccompanied by fundamental changes in the rotation law. Within the photosphere, however, a very different condition of things must exist. In fact, the reversal of spot polarity provides a possible clue to the cause of the sun-spot cycle, strongly suggesting, to say the least, that its seat is within the sun, in spite of all attempts to explain the cycle as a result of the influence of planetary or other external phenomena.

The inclination of the solar magnetic axis, now definitely shown to make an angle of about 6° with the sun's axis of rotation, will provide food for thought to students of the earth's magnetism. Two bodies, the earth and the sun, rotating in the same direction, are now known to be magnets of the same polarity, with magnetic axes which fail to coincide with their rotation axes. The analogy, it may be hoped, will serve as a useful guide to the theoretical studies of magneticians.

The successful investigator must devote much of his attention to the elimination of sources of error and the critical investigation of plausible hypotheses, even though the latter may prove in the end to be false guides. The relativity hypothesis indicates that the lines of the solar spectrum should be shifted very appreciably toward the red when compared with the corresponding lines in terrestrial sources. The test is rendered extremely difficult by the conditions existing in terrestrial light-sources, which produce peculiar and variable shifts of the lines that must be used as standards; but through persistent and painstaking work these difficulties have been overcome, thus furnishing reliable standards of comparison and supplying a negative answer to the relativity criterion. The uncertainties experienced in measuring the members of closely adjacent pairs have also been reduced, and the displacing effect of scattered light has been shown to be negligible under the conditions existing on Mount Wilson. Thus the way has been prepared for the study and elucidation of the most minute shifts of solar lines.

While solar research still retains its prominent place in the work of the Observatory, the development of stellar and nebular investigations continues to increase. The direct photography of nebulæ has not only recorded new and interesting details of structure, but has also revealed the prevalence in these objects of faint temporary stars, whose tendency to form in the branches of spiral nebulæ strongly suggests an important analogy with the well-known fact that bright temporary stars invariably blaze out in or near the Milky Way. The classic problem of "island universes" is again under vigorous discussion, and much attention will be paid here to its further investigation.

The distances of the stars, so fundamental a factor in all astronomical studies, whether structural or physical, are now determined by two methods. The first involves the simple trigonometrical principle of measuring the displacement of a star's position, as observed from opposite extremities of the earth's orbit. From this accurately known base-line their distances are readily calculated, precisely as in terrestrial triangulations. The high precision of differential measurements obtainable with such an instrument as our 60-inch reflector would seem to make this method very reliable. Insidious systematic errors, however, may enter to vitiate the conclusions. It is therefore satisfactory to find, as the result of careful study, that these are apparently very small.

The use of the second method, recently devised here and described in the last annual report, has led to extensive and highly significant developments. By this method every good photograph of a star's spectrum yields a measure of its distance, given by a simple determination of the relative intensities of certain lines. The limitation of application to the more advanced types of spectra has been partially removed by the inclusion of new groups of lines, which serve as criteria in the earlier types. Moreover, any doubts that may have existed as to the accuracy of the method have been dispelled by a comparison of the spectroscopic and trigonometric parallaxes of 360 stars, which shows an exceedingly satisfactory agreement. The rapidity and simplicity of the method will therefore at once lead to extensive applications.

The first of these, involving an investigation of the relationship between the absolute magnitudes and motions of some 1,300 stars, clearly indicates an increase of velocity with decrease in absolute magnitude, independent of distance from the sun. The conclusion that the intrinsically fainter stars move more rapidly than the brighter ones must prove of exceptional significance in the theory of stellar evolution. Another interesting conclusion, in harmony with previous results for stars of earlier types, is the marked condensation of the later-type stars of high luminosity in the plane of the Milky Way.

The extensive task of determining the photographic magnitudes of stars in 115 of the Selected Areas of Kapteyn has been essentially completed, and work on the photovisual magnitudes is also advancing. The former results have afforded means for a study of the increase in the number of the stars toward the plane of the Milky Way. From counts of 40,000 stars, a reliable measure of the relation between stellar density and galactic latitude has been deduced which is in harmony with Professor Kapteyn's conclusion that the faint stars show a high galactic condensation. This result is further confirmed by a discussion of Professor Turner's counts of some 600,000 stars in the Astrographic Catalogue. Stars of photographic magnitude 17.5 are from twenty to thirty times as numerous in the plane of the Milky Way as at its poles.

The continuation of a comprehensive investigation of globular star clusters has yielded new and interesting results. Thus it appears to be possible to estimate the relative distances of clusters containing typical short-period variable stars, since the median magnitudes of these objects are constant for each cluster, while varying from one system to another. The method, if substantiated by further work, will be of great value, in view of the extreme remoteness of these objects, which places them beyond the reach of other means of measuring distances.

Another outcome of this investigation is the discovery that the distribution of the fainter stars in certain globular clusters reveals an apparently characteristic elliptical form. In Messier 13, for example, there is an axis of elongation along which the stars are 30 per cent more numerous than along the minor axis. As this result is supported by other phenomena, it may prove that the so-called globular clusters are actually more or less flattened spheroids, analogous to our own galactic system. Additional work on clusters shows no evidence of effectual scattering of light in space and indicates provisionally that the depth of the Milky Way in some directions may exceed 25,000 light-years.

The Observatory's policy of devoting special attention to laboratory investigations for the interpretation of solar and stellar phenomena has been continued with the aid of improved facilities. The electric furnace has been used for the study of anomalous dispersion phenomena and for the investigation of the effect of changes in temperature, vapor density, and surrounding atmosphere on the spectra of iron, calcium, strontium, and barium. The very diffuse arc lines of barium are sharp and of modified structure in the furnace, where a triplet or doublet sometimes appears in the place of the single arc line. Measurements of the sharp furnace lines indicate their apparent agreement with faint unidentified lines of the solar spectrum, where their structure corresponds with that given by the furnace. The series lines of calcium, produced by the impact of cathode rays, show marked differences of intensity as compared with their appearance in other sources.

The further study of the effect of an electric field on radiation, which has now been extended to include the spectra of iron, chromium, nickel, titanium, and manganese, has shown no appreciable effect for the great majority of lines; 74 lines of chromium, 8 of iron, and about

12 of nickel, however, exhibit either displacement or decomposition in an intense electric field. It is interesting to find that under these conditions the relative intensity of the lines is unlike that given by the arc, spark, or furnace.

The important task of determining the wave-lengths of lines serving as primary and secondary standards has already been mentioned. This has now reached a point where many of the unstable lines of iron can be safely used, providing that suitable precautions be taken in the adjustment of the electric arc. In this connection the displacing effect of the spark on lines of iron has been determined and the pressure shifts of iron lines have been remeasured, with improved apparatus, to eliminate pole effect.

The chief work of construction has included the enlargement of the Pasadena physical laboratory to nearly double its former area; the erection of a two-story concrete dormitory on Mount Wilson, adjoining the Monastery, to provide for the increased staff required for the 100-inch telescope; and the essential completion of the dome and mounting for this instrument. The erection on Mount Wilson of a 75-foot steel flagpole, flying a large American flag, for both of which we are indebted to Mr. Edward D. Adams, should also be recorded here as an appropriate event of the year.

As the Director has had so small a part in the year's activities, he may be permitted to express his pleasure in the important advances made in every department of the Observatory's work and his high appreciation of the faithful and devoted services of every member of the staff. It is well to remember that all forms of scientific research represent a very real service to the state. Astronomy is not so remote from the practical affairs of life as a superficial estimate might conceive it. Poincaré has shown this most clearly in his book on *The Value of Science*, where he asks how far advanced the world's civilization would be if the stars had always been hidden by clouds. It is interesting to observe that in demonstrating the part played by astronomy in the world's progress he does not even mention such important matters as navigation and the determination of time, because of their insignificance as compared with far more impressive contributions. Thanks to observatories in all quarters of the earth, the picture of the universe still continues to unfold and to influence progress in every field of thought. We are happily in a period of unprecedented progress, when the empirical conceptions of an earlier time are rapidly giving place to well-grounded views. The privilege of aiding in this advance, at a time when the pioneer stage has not yet been passed, will be appreciated by those who reflect on the true meaning and influence of astronomical discovery.

STAFF.

Such time as the Director could give to astronomy during the year has been mainly devoted to solar investigations, continued in collaboration with several members of the staff. Dr. Walter S. Adams, Assistant Director, has pushed forward his investigations in stellar spectroscopy and has had general charge of the Observatory during the Director's absence. Professor Frederick H. Seares, superintendent of the Computing Division and editor of the Observatory publications, has continued his researches in stellar photometry, the determination of the position of the sun's magnetic axis, and other subjects. Dr. Arthur S. King, superintendent of the Physical Laboratory, has carried on various investigations with the electric furnace. Dr. Charles E. St. John has given most of his attention to the determination of the fundamental wave-lengths of solar and standard lines, with special reference to a possible relativity effect. Professor G. W. Ritchey has remained in charge of the work of the optical shop and has continued the photography of nebulæ with the 60-inch reflector. Dr. J. A. Anderson has devoted most of his time to the study of the Stark effect. Mr. Harold D. Babcock has continued his investigations on standards of wave-length and related subjects. Mr. Ferdinand Ellerman has given much of his time to solar observations and has served as Observatory photographer. Mr. Francis G. Pease, in charge of instrument design, has given special attention to the 100-inch telescope, besides continuing his photographic work on nebulæ and star clusters. Dr. Harlow Shapley has advanced his investigations of star clusters, variable stars, and stellar photometry. Dr. Adriaan van Maanen has continued his determinations of stellar parallaxes and the measurement of spectra to fix the position of the sun's magnetic axis. Dr. Seth B. Nicholson has given most of his attention to solar observations and has calculated the orbit of the ninth satellite of Jupiter. Professor Alfred Joy, who has been engaged in stellar spectroscopic work, has also taken part in the solar observations. Dr. Gustav Strömberg has devoted himself to the study of the stellar spectroscopic results. Mr. Ray Campbell assisted in the solar observations until May, when he resigned his position. His work was continued by Dr. Walter T. Whitney from that time until the end of August, when Mr. Arthur S. Dockham joined the staff to assist in these investigations.

Professor J. C. Kapteyn, for ten years Research Associate of the Institution, has not been able to visit Mount Wilson since early in the war. He is actively continuing his work in Groningen, however, and we are providing material for some of his investigations.

The members of the Computing Division have assisted in the work of the various departments as follows: Miss Ware and Miss Miller have been engaged with the solar investigations carried on by Dr. St. John. Miss Burwell, Miss Stone, Miss Shumway, and, for a part of the time, Miss Brayton, have made measures and reductions relating to stellar spectroscopy. Miss Richmond, Miss Joyner, Miss Carolyn Burns, Miss Winn, and Miss Davis have been occupied with stellar photometry, and Miss Richmond has assisted Mr. Pease and Dr. Shapley with the discussion of an extensive series of counts on photographs of clusters. For part of the year Miss Davis was also occupied with reductions of parallax measures for Dr. van Maanen. Miss Wolfe has given her time to reductions of stellar parallax and the sun's general magnetic field. She has also done miscellaneous computing and photographic work, and has assisted in the library. Miss Margherita Burns and, for the latter part of the year, Miss Brayton, have been engaged with the work of the Physical Laboratory. Miss Connor has continued as librarian and has assisted with the editorial work.

Dr. J. van der Bilt served as a volunteer assistant on Mount Wilson from September to January. Mrs. Harlow Shapley has continued her service as a volunteer assistant in connection with the work in stellar photometry. Miss Edna Carter, Associate Professor of Physics at Vassar College, who began work last year as a volunteer assistant in the physical laboratory, is still devoting her attention to metallic spectra produced by the cathode discharge. Mr. Hugo Benioff has served for two months as volunteer assistant on Mount Wilson.

Mr. L. B. Aldrich has continued the work of the Smithsonian Astrophysical Observatory on Mount Wilson during the summer of 1917.

INVESTIGATIONS IN PROGRESS.

SOLAR RESEARCH.

Few changes have been made during the year in the equipment for solar observations. The final details in the remodeling of the Snow telescope and the installation of the new vertical spectrograph have been delayed by the pressure of other work in the instrument shop, but it is hoped that these important improvements may soon be completed.

A small but valuable addition to the 75-foot spectrograph consists of a parallel-plate micrometer, mounted in the plate-holder support, and serving for daily visual measures of the strength of the magnetic fields in sun-spots.

SOLAR PHOTOGRAPHY.

During the year ending August 31, 1917, the following photographs were taken with the 60-foot tower telescope by Messrs. Ellerman, Nicholson, Joy, van der Bilt, Campbell, Whitney, and Benioff: photoheliograms of 6.5-inch image, 307 on 307 days; 5-foot spectroheliograms (*Hα*, entire 6.5-inch disk), 298 on 298 days; 13-foot spectroheliograms (K and *Hα*, 2-inch disk and prominences; *Hα*, portions of 6.5-inch disk), 1,248.

Photographs of spectra made with the 75-foot spectrograph of the 150-foot tower telescope include 124 of the disk for the sun's general field, 80 of sun-spots, and 15 for miscellaneous purposes.

Beginning May 20 and ending September 28, 1916, the sun was photographed on 132 consecutive days.

During the summer of 1917 there was much partial cloudiness; for over five weeks some clouds formed every day.

STEREOGRAMS OF CALCIUM AND HYDROGEN FLOCCULI.

The interesting results obtained last year by combining $H\alpha$ images of the disk for stereoscopic study have been extended, with special reference to the elimination of false effects of relief frequently encountered in such work. If two photographs of distant mountains, taken from the extremities of a long base-line, are wrongly combined for stereoscopic vision (left for right), the eyes easily see the lower mountains in the foreground as a deep cave, but reverse the peaks with great difficulty. The tendency to persist in seeing such forms in their normal relief doubtless explains the impossibility of reversing certain stereograms of $H\alpha$ flocculi near the limb, where the time interval which separates the two photographs is more than sufficient to give true stereoscopic vision.

It is obvious, however, that the surest results and the best sense of relief will be obtained by combining images well separated in time, provided that the changes in form of the flocculi and prominences during the interval are not too serious. An admirable appearance of sphericity of the solar image and high relief of the prominences on the disk results from the stereoscopic combination of two $H\alpha$ photographs of small diameter, separated by an interval of 3 hours. Any false effects caused in certain prominences by changes in form can be detected by the use of various pairs of photographs made at different times.

The value of this method is obvious, especially in the study of prominences on the solar disk. No one can doubt their character when seen in this way, or make the mistake of attributing the dark flocculi on $H\alpha$ images to other causes.

MAP OF THE SUN-SPOT SPECTRUM.

As stated in the last annual report, our new map of the sun-spot spectrum, on a scale of 1 cm. to the angstrom, was completed last year by Mr. Ellerman for the region λ 6000 to λ 6450. During the winter enlargements were made from additional negatives for the region λ 5400 to λ 6000, and new negatives have now been obtained which will permit the entire region from λ 3800 to λ 6600 to be included in the map.

INCLINATION OF THE LINES OF FORCE IN SUN-SPOTS.

In the last report reference was made to the differences in the polarization of Zeeman triplets observed in various parts of a spot near the sun's limb. These correspond with what would be expected on the assumption that the lines of force at the center of the spot are nearly parallel to a solar radius, and that the angle they make with the surface decreases in going outward to the edge of the penumbra. In the case of small spots very close to the limb it is difficult to see the lines of force (directed toward the observer) on the edge of the penumbra lying nearest the center of the sun, but in large spots this difficulty is not experienced. It goes without saying that a single symmetrical spot is needed to bring out the effect properly, for if companions are present the lines of force are distorted, with corresponding changes in the polarization phenomena.

If a single symmetrical spot is watched as it crosses the sun's disk, the changes in the polarization phenomena are generally such as would be expected from the above characteristics of the lines of force. When the spot is near the center of the disk, plane polarization is best seen near the edges of the penumbra, where the lines of force are nearly normal to the line of sight. It sometimes happens, however, that the central component of triplets remains visible in spots near the center of the sun, where its intensity would be very small if the lines of force were really radial. Very interesting polarization phenomena are observed in complex sun-spots, especially in regions between closely adjacent spots of opposite polarity.

SUN-SPOT POLARITIES.

Sun-spots have been so numerous that the magnetic polarities of nearly 40, on an average, have been observed each day with the 75-foot spectrograph of the 150-foot tower telescope. These of course include the small members of large spot-groups. With the aid of a parallel-plate micrometer it has also been possible to measure visually the strength of the magnetic fields in a large percentage of these spots.

Throughout the year a new system of recording has been employed. All spots of the 16-inch solar image at the focus of the 150-foot tower telescope are traced on a large sheet of paper, and their polarities and field-strengths are also indicated on the drawing. Thus our present records are much more complete than those obtained formerly.

In spite of the peculiarities of complex spot-groups, in which the simple features of bipolar spots are frequently lacking, the fact remains that bipolar structure is almost invariably observed. That is to say, most spot-groups, however complex, can be divided into two regions of opposite magnetic polarity, though it sometimes happens that minor companion spots are not of the expected sign. Cases are not uncommon in which a second bipolar group, or one of its members, appears close beside another group. These deserve careful study in the future.

Classifying the spots on the bipolar basis, and counting single spots as though they were the preceding members of such groups, Mr. Nicholson has tabulated their polarities as shown in the table. The data include all spots whose polarities were observed during the years 1913 to 1916, inclusive. The term "regular" as applied to the polarity of spots or the direction of whirl in the overlying *Hα* flocculi indicate that the observations thus designated are in harmony with the rule given in the last report.

Hemisphere.	Direction of *Hα* whirl.				Polarity.		
	Regular.	Irregular.	None.	Undetermined.	Regular.	Irregular.	Undetermined.
North	87	24	50	148	257	10	42
South	68	20	22	135	202	8	35
Whole sun	155	44	72	283	459	18	77

It will be observed that in the case of spot polarities the number of exceptions to the rule is small—18 in a total of 459. Of these, 8 are of the spot type classed by the Greenwich observers as "faint markings"; 3 of the remaining 10 were observed on one day only, without check observations; and 1 was a complex group in which the largest member was regular. The flocculi, however, are much less uniform in behavior. The exceptional cases should prove of great interest.

As stated last year, the polarities of the spots reversed at the spot minimum, while the direction of the *Hα* flocculi showed no change. An interesting case is afforded by a photograph in which two single spots of the same polarity, widely separated on the solar surface, are accompanied by *Hα* flocculi indicating opposite directions of whirl. The sun-spot maximum has hardly yet been reached, but if any reversal of polarities is to occur at that time, no indication of it has yet been detected.

"HYDROGEN BOMBS" NEAR SUN-SPOTS.

Observations made in previous years on the great widening of *Hα* in small eruptive regions in the penumbra, or at other points near active sun-spots, have been frequently repeated. The regions in question are very small, usually only a few seconds of arc in diameter. The narrow *bright* wings of *Hα* corresponding to them frequently extend several angstroms on either side, fading in intensity toward their extremities. Mr. Ellerman has recently succeeded in making some good photographs of these spectral phenomena, which are very short-lived.

GENERAL MAGNETIC FIELD OF THE SUN.

The investigation for determining the inclination of the sun's magnetic axis and the period of its revolution about the solar axis of rotation has been continued; 632 spectra have been measured by Mr. van Maanen, representing observations on 19 days. The work, which has involved the measurement of 2,132 plates during the last three years, is now nearing completion. From observations on 63 days, distributed over an interval of 110 days for which plates are available, new values for the inclination and the period have been derived. The reduction of the measures and the necessary computations were made by Miss Wolfe under the superintendence of Mr. Seares. The results are:

Period $= 31^{d}.79 \pm 0^{d}.31$ Inclination $= 6^{\circ}.2 \pm 0^{\circ}.4$
Magnetic pole on central meridian, 1914, June 25.31 ± 0.42 G. M. T.

The data give some indication that the inclination is not constant; this, however, may be due to accidental errors or possibly to the influence of spots and those features which have been called "faint markings" by the Greenwich observers, though none of these were seen when the photographs were taken. In general, days on which spots were near the sun's meridian were avoided. To investigate the influence of the "faint markings," some photographs of their spectra have been taken; measures of a few of these show rather strong magnetic fields, of the order of 100 to 150 gausses. It is clear that if many of these local fields were present when the plates were taken for the investigation of the position of the sun's magnetic axis, they may have been a disturbing factor in the derivation of the inclination. It will therefore be necessary to see if these markings, first mentioned by the Greenwich observers in January 1915, are visible near the spot minimum or appear only during the time of increasing activity.

THE EQUIVALENCE PRINCIPLE OF RELATIVITY.

Mr. St. John's investigations on the accurate determination of the positions of solar and terrestrial lines have been utilized in several specific problems, among them a test of the relativity hypothesis as applied to the solar atmosphere.

According to Einstein's generalized equivalence principle of relativity, the lines in solar and stellar spectra should be displaced to the red when referred to the corresponding terrestrial lines. The calculated displacements, equivalent in the case of the sun to the Doppler effect of a velocity of 0.634 km. per sec., are well within the range of solar measurements. An extended investigation based upon the behavior of lines in the nitrogen (cyanogen) band at λ 3883 was undertaken to determine what consideration should be given to this deduction from the equivalence principle in the interpretation of observations of solar spectra. These lines lend themselves to the purpose, as they are not displaced by pressure; freedom from Doppler effect is obtained by making the observations at the polar limb. Emphasis was placed upon the selection of the lines used, with a view to precision of measurement and freedom from blends. The wave-lengths were measured at the sun's center and limb and in the carbon arc in terms of identical iron standards, and their solar wave-lengths were redetermined on the Rowland system. The displacements, sun *minus* arc, were determined at the center by direct comparison and by three indirect methods; the displacements, limb *minus* arc, were derived by two methods, with results as shown by the table.

No. lines.	Intensity.	At center.	At limb.
25	00 to 1	−0.0009	....
18	2 to 4	+0.0013	....
17	00 to 1	....	0.0000
18	2 to 4	....	+0.0036

The observations of greater weight, those upon low-level lines of intensity 00 to 1, indicate a slight upward movement of the vapor over the center of the disk. A possible explanation from the relativity point of view is that the displacement toward the red has been overbalanced by a Doppler effect; but at the limb, where the Doppler effect of such a motion would be zero, the solar and arc wave-lengths are equal.

If the means for all lines be considered, the displacement at the center of the disk is zero and at the limb 0.0018 Å toward the red. Within the limits of error there is accordingly no evidence in these observations of displacements in the direction of longer wave-lengths, either at center or at limb, of the order of the 0.008 Å required by the equivalence principle of relativity as developed by Einstein.

ERRORS IN THE MEASUREMENT OF CLOSELY GROUPED LINES.

A further investigation of the errors incidental to the measurement of pairs of closely adjacent lines is being carried on by Mr. St. John with the aid of artificial complexes in which the actual separation and relative intensities of the components are known. This promises to yield results valuable for solar work, as the appearance of combinations of solar lines can be simulated with a high degree of perfection. Preliminary data show that for a doublet in which the maximum of one component coincides with the first minimum of the other (the usually accepted limit of spectrographic resolution), the measured separation is 0.430 mm., while the actual separation is 0.380 mm. The combination reproduces approximately the appearance and scale of a solar pair in a fifth-order spectrogram of the 30-foot spectrograph separated 0.1 Å. The error represents an over-separation of 0.013 Å, a confirmation of the previous determination of the errors in the Rowland table for close pairs. The investigation promises a means of fixing the limits beyond which the measurements of an individual observer are reliable and of determining approximately his systematic error within such limits.

The multiplicity of causes which may be concerned in the displacement of lines in terrestrial and solar spectra rendered much preliminary investigation necessary before a hopeful attack could be made upon the problems involved. Investigations of the preceding year showed that, within the limits of error, systematic effects of anomalous refraction are absent from the general disk of the sun, while those of the present year have shown the absence of displacements required by the equivalence principle of relativity, and have developed a source of iron lines free from the disturbing influences of pole effect. By the elimination of anomalous refraction and relativity, and the development of a source by comparison with which the relative displacements of the iron lines in solar and arc spectra may be referred to conditions in the solar atmosphere, it is possible to attack the related solar problems with greater prospect of success.

It becomes increasingly evident that data based upon several elements and covering an extended range of wave-length will be necessary for definitive determinations, and that further investigation should be made of conditions obtaining near the solar limb. Investigations now in progress bear upon these questions and have for an immediate end the establishment of a system of solar standards in terms of international units. These standards will eventually be derived from three sets of observations, for which an interferometer and two spectrographs are available.

SOLAR ROTATION.

The series of plates at solar latitudes 0° and 45° is being continued with the 150-foot tower telescope, with the object of obtaining observations over an extended period under as nearly as possible the same instrumental conditions. In view of the differences found by observers, it is desirable to have a long homogeneous series for determining whether the indicated variations in solar rotation period are real or depend upon instrumental conditions and personal equation. Observations with the 150-foot telescope will be compared with simultaneous observations made with a duplicate prism system used, sometimes with the 60-foot tower telescope and sometimes with the 60-foot Snow instrument, the advantage of the latter being the complete achromatism of the solar image.

The total variation found in the results for the years 1914, 1915, 1916, and 1917 is about 3 per cent. This difference, however, is not between the values for the extreme dates and can not be ascribed to a secular or long-period variation in the rotation rate. It is probably due, in part at least, to local drifts in the sun's reversing layer.

The question whether atmospheric haze and scattered light can influence the results obtained in solar rotation observations has also been examined by Mr. St. John. Observations were made with the regular rotation apparatus and the 150-foot tower telescope, the light from a point 0.5 per cent of the radius outside the sun's limb being compared with that from a point 1.5 per cent within the limb, where the slit is set in the usual rotation observations. When the limb spectrum was fully exposed, there was no trace of a spectrum from the light outside the limb, and a factor of about 100 in the exposure times was necessary to obtain equality of densities. This is in agreement with the results found by Mr. Abbot, who, from observations on the distribution of light along the diameter of the solar image, concluded that the stray light from all sources at a point 1.5 per cent of the solar radius outside the limb is much less than 1 per cent of the sunlight at the limb for the region of the spectrum employed in rotation observations.

The measurement and reduction of the photographs required for these investigations by Mr. St. John have been carried out by Miss Ware and Miss Miller. Miss Ware has measured the solar-rotation negatives, while Miss Miller has dealt with those used in the study of the relativity effect.

INVESTIGATIONS OF STARS AND NEBULÆ.

OBSERVING CONDITIONS.

The weather conditions for night observations during the year ending August 31, 1917, were somewhat below normal. This was especially noticeable during the months of May and July, which were

Date.	Hours of darkness.	Hours clear.	Hours cloudy.	Hours lost silvering and repairing.	Hours of exposure time.	Observations.		
						All night.	Part of night.	None.
1916.								
September	295	226	69	0	173	21	4	5
October	336	191	145	0	149	15	6	10
November	330	221	95	14	156	13	10	7
December	346	168	178	0	127	10	7	14
1917.								
January	346	179	167	0	142	13	8	10
February	308	129	179	0	100	7	7	14
March	324	201	123	0	139	15	11	5
April	286	173	95	18	121	15	5	10
May	266	148	117	1	111	15	3	13
June	230	207	22	1	156	25	2	3
July	255	173	81	1	123	13	13	5
August	269	256	13	0	195	26	5	0
Totals	3,591	2,272	1,284	35	1,692	188	81	96

characterized by an exceptional amount of cloudiness. The 60-inch reflector was in use 188 entire nights and parts of 81 nights. No observations were made on 96 nights. Out of 3,591 hours of darkness the instrument was in use 2,272 hours, or 63 per cent of the time. The statistics for each month are given on the preceding page. The mirror was resilvered in November and April.

The total exposure time for the year was 75 per cent of the observing time and 47 per cent of the hours of darkness. The observing conditions as regards seeing (on a scale of 10) and wind velocity are given in the accompanying table:

Seeing.		Wind.	
1	45 nights.	Very high	24 nights.
2	35	Brisk	37
3	47	Moderate	50
4	61	Light	139
5	57	Calm	100
6	24		
7	7		
8	1		

A standard self-recording anemometer provided by the United States Weather Bureau was installed on Mount Wilson in April and has been in service since that time, furnishing continuous records of the wind velocity. Since May 1 the highest recorded velocity during any five minutes was 30 miles per hour on May 5. The average velocity May 1 to August 31 was 6.7 miles per hour.

The precipitation during the year was 28.41 inches, the largest amount occurring in January. The snowfall amounted to 72 inches. Much fog occurred during the spring months, especially in the month of May. The maximum temperature was 98° F. on June 17; the minimum 10° F. on January 16.

PHOTOGRAPHS OF NEBULÆ AND CLUSTERS.

Photographs of the following spiral nebulæ were made during the year by Mr. Ritchey at the primary focus of the 60-inch reflector; the exposure times varied from 80 minutes to 465 minutes: N. G. C. 628, 650, 891, 3031, 5194–5, 6412, 6946, 7331, 7814. A close group of five spiral nebulæ in Pegasus was also photographed.

An interesting feature of the results was the discovery by Mr. Ritchey of a star on the photograph of the spiral nebula N. G. C. 6946 which did not appear on five photographs taken between 1910 and 1916. Several additional negatives confirmed the reality of this nova. The star was of about the fourteenth magnitude on July 19, 1917, and about one magnitude fainter on July 27. It occurs in one of the outer arms of the spiral at a distance of 2′ from the nucleus. A spectrogram taken with very low dispersion and without a slit on August 16 indicates a fairly strong continuous spectrum upon which bright bands appear to be superposed.

The discovery of this nova led to a careful reexamination of other photographs of spiral nebulæ. As a result two stars were found near the center of the Andromeda Nebula which, in all probability, are also to be classed as novæ. Fortunately an extended series of photographs of this object taken in 1909 and 1910 was available. Both stars were invisible on a negative of August 13, 1909; were faint on a plate of September 12; became bright on September 15 and 16; then grew fainter and were just visible on November 7. They were not seen after that date. At maximum these stars were of about the sixteenth magnitude.

Mr. Shapley and Mr. Pease have each found one nova on our photographs of spirals, while Mrs. Isaac Roberts has found one on photographs taken by her late husband, and Dr. Curtis has found three on photographs made with the Crossley reflector. The further investigation of such objects will undoubtedly prove to be a matter of great importance in the study of spiral nebulæ.

Mr. Pease obtained during the year 30 photographs of the following nebulæ and star clusters, with exposures ranging from 15 minutes to 5 hours 30 minutes:

N. G. C.	Type.	N. G. C.	Type.
894–5	Spiral	6914	Not seen
1931	Gaseous	7048	Planetary
2366	Gaseous	7067	Group of stars (vis. obs.)
2903	Spiral	7129	Gaseous
3357	Nebulous star	7226	Group of stars (vis. obs.)
3367	Spiral	7240	Many small nebulæ, spirals, and nebulous spots
3379	Nucleus in circular nebulosity	7243	Group of stars (vis. obs.)
3384	Nucleus in elongated nebulosity	7436	Several very small spindle nebulæ
3389	Spiral	No. in Ind. Cat. I.	
3391	Spiral		
3395–6	Spiral	1363	Star field (vis. obs.)
6820	Gaseous	1369	Group of stars (vis. obs.)
6846	Small group of stars	1378	Not seen
6888	Gaseous	1470	Gaseous

The cluster photographs were mainly for the purpose of securing star counts, while those of the nebulæ were for classification and determination of type—whether spiral, gaseous, or planetary. Several visual observations are included as well.

A photograph of N. G. C. 1555, Hind's Variable Nebula, taken on November 27, 1916, when compared with earlier negatives, showed marked changes of form in the nebula. The most important difference was in that portion near the variable star T Tauri.

JUPITER'S NINTH SATELLITE.

Using the 1915 observations, an improved determination of the orbit of Jupiter's ninth satellite was made by Mr. Nicholson, and an ephemeris was computed for the 1916 opposition. The satellite was found near the computed place on four negatives taken by Mr. Shapley with the 60-inch reflector. Its position was measured on these plates and the orbit corrected by the aid of the observations at three oppositions, 1914, 1915, and 1916. The positions of three new asteroids were also obtained from the plates.

MEASUREMENTS OF PARALLAXES AND PROPER MOTIONS.

At the 80-foot focus of the 60-inch reflector 402 plates with 535 exposures were taken by Mr. van Maanen, as follows:

	Plates.	Exposures.
For parallax	289	418
For proper motion	98	98
Miscellaneous	15	19

The measures and reductions for 20 parallax fields have been completed, thus giving a total of 54 finished fields. Most of the stars measured are of the later spectral types, of magnitudes 5 to 7, and of proper motions less than 0″.5 annually. The results for the first 50 fields have been discussed for systematic errors in several ways:

1. The parallaxes of the 396 comparison stars, arranged according to brightness, seem to indicate a systematic error of +0″.001 in the parallaxes of the principal stars.
2. The neglect of the quadratic terms of the coördinates of the comparison stars has caused no systematic error.
3. A comparison of five fields observed in common with other observers shows no appreciable error.
4. A comparison of the proper motions in right ascension derived here with those given by Boss indicates a systematic error of −0″.001.
5. A comparison of the Mount Wilson parallaxes with those derived from van Rhijn's tables gives a difference of +0″.007.
6. A comparison of 47 of the parallaxes with those determined by Mr. Adams by his spectroscopic method indicates an error of +0″.003.
7. A comparison with the mean of the parallaxes determined by other observers for 68 stars of the same spectral type, magnitude, and proper motion points to a systematic error of −0″.001.

The only large difference is revealed by the comparison with van Rhijn's tables; there are several reasons, however, for believing that this can not be wholly due to the Mount Wilson parallaxes. From all material available it is probable that the latter have no systematic error exceeding 0″.003.

Several nebulæ have been included in the observing program. The following values of their parallaxes have been determined for three fields:

N. G. C.	Type.	Relative π.	P. E.
5194	Spiral	$0''.000$	$\pm 0''.010$
6720	Ring	$+0.002$	± 0.005
7662	Planetary	$+0.021$	± 0.004

The value for N. G. C. 5194 is preliminary, as it was derived from 10 exposures only. For Barnard's star of large proper motion the preliminary parallax, also from 10 exposures, is $+0''.519 \pm 0''.005$.

During the middle of the night, when the parallax factors are too small for measures of distance, the work on stars of large proper motion has been continued. First-epoch plates have now been taken for 170 stars, while for 12 fields second-epoch plates have been secured. No new companions, except that of Pi 2^h 123, mentioned in the last report, have been found. It should be noted that most of the fields for which second-epoch plates have now been secured are those of stars with very large proper motions, whose fields have been under observation for considerable time; three of them were already known to have companions.

For the reduction of the parallax measures Mr. van Maanen has had the assistance of Miss Davis for part of the time, and, more recently, that of Miss Wolfe.

STELLAR PHOTOMETRY.

The observational part of the investigations in stellar photometry by Mr. Seares and Mr. Shapley includes 522 photographs, all made with the 60-inch reflector and distributed as follows: Selected Areas, 208; clusters, 189; variable stars, 55; color photographs of stars, 19; miscellaneous, 51.

PHOTOGRAPHIC MAGNITUDES FOR THE SELECTED AREAS.

So far as the original program is concerned, the observational part of this investigation, which is in the hands of Mr. Seares, is now prac-

Kind of photograph.	Photographic magnitudes.		Photovisual magnitudes.	
	Required.	Obtained.	Required.	Obtained.
Magnitude scale.....	556	474	111	59
Zone comparison....	276	226	72	10
Polar comparison....	92	68	74	15
Totals.........	924	768	257	84

tically completed. At the urgent request of Professor Kapteyn, however, an additional zone of 24 areas has been added, in order that he might be supplied with standards at −15°. This increases the number of regions to a total of 139. The table on the preceding page refers to the enlarged plan.

During the past year the extensive reductions involved in this investigation have been carried on by Miss Richmond, Miss Joyner, Miss Carolyn Burns, and Miss Winn, with occasional assistance from Miss Wolfe. With one or two exceptions, the measures of the diaphragm photographs now available have been finished. For 102 of the areas the reductions are complete up to and including the relative magnitudes; and for each of these regions Professor Kapteyn has been supplied with a sequence of standard magnitudes, which he is using for the reduction of the Durchmusterung photographs of the Selected Areas.

PHOTOVISUAL MAGNITUDES FOR THE SELECTED AREAS.

The plans of Mr. Seares and Mr. Shapley for this investigation were outlined in the preceding report. Photographs have been obtained whenever the arrangement of the program for other photometric investigations permitted. As indicated by the table, about one-third of the photographic work has been finished.

DISTRIBUTION OF STARS WITH RESPECT TO THE GALACTIC PLANE.

The increase in the number of the stars as the Milky Way is approached from either side is a fact long established, and for objects brighter than the eighth or ninth magnitudes there is substantial agreement in the amount of the galactic condensation found by different observers; for the fainter stars, however, the value of the concentration has until recently been affected with much uncertainty.

The photometric results for the Selected Areas are still incomplete, but those now available contribute materially to a more definite knowledge of stellar distribution. From counts of about 40,000 stars on photographs of 88 areas well distributed in galactic latitude, Mr. Seares has derived the relation between stellar density and latitude for the magnitude limit of the plates, which provisionally is placed at 17.5 on the Mount Wilson photographic scale.

The data were first compared with the density tables of Kapteyn. The limiting magnitudes corresponding to the observed densities were interpolated from these tables and combined to form the mean limiting magnitude of the counts on the scale used by Kapteyn. The result, which is 16.3, deviates largely from the limit on the Mount Wilson system and indicates an important divergence of scale, but this is unimportant for the comparison. The differences between the logarithms of the observed numbers of stars and the numbers interpolated from Kapteyn's tables for the average limit of 16.3 are in the second column of the accompanying table. Although systematic, these differences are small, and the Mount Wilson counts therefore agree with the results of Kapteyn in showing for the faint stars a high value of the galactic condensation.

Additional evidence is as follows: In his *First and Second Reports on the Progress of the Plan of the Selected Areas*, Kapteyn gives counts for 127,315 stars on 54 photographs of Southern Selected Areas made at Arequipa. The limiting magnitude for these photographs is practically the same as that for the Mount Wilson series. A comparison gives the differences in the third column of the table; these also are satisfactorily small. On the other hand, a similar comparison with the densities of Chapman and Melotte reveals the discordant results in the fourth column.

(Unit=0.01 in logarithm.)

Gal. lat.	MW *minus* Kapteyn.	MW *minus* SSA.	MW *minus* C and M.	Astrographic zones *minus* Kapteyn.				
				8.5	9.5	10.5	11.5	12.5
5°	− 5	+5	+74	−2	0	0	−2	−3
15	0	−3	+57	0	+2	+2	+2	+2
25	− 5	−7	+37	+1	+2	+4	+4	+4
35	− 7	−6	+29	+2	+1	+2	+2	+4
45	− 4	0	+28	+2	−2	−1	0	+2
55	+ 1	+4	+13	+1	−3	−3	−1	+2
65	+ 7	+5	+ 8	+1	−3	−3	0	+2
80	+12	(+4)	+ 4	0	−1	+1	−1	−1

A very valuable mass of data, including counts of about 600,000 stars from zones of the *Astrographic Catalogue*, has recently been collected by Turner. These also have been reduced to densities and compared with Kapteyn, and the differences in the logarithms for various magnitude limits on the scale of *Groningen Publication* No. 18 are in the last five columns of the table. The faintest limit is here only 12.5, but this is well below the point at which Kapteyn's densities begin to diverge from those of Chapman and Melotte; the astrographic counts are especially valuable as evidence on the distribution of stars of intermediate brightness.

Although the magnitude scale of *Groningen Publication* No. 18 seems to require some correction, these various comparisons afford a striking confirmation to the sixteenth magnitude (Groningen scale) of the values of the galactic condensation found by Kapteyn. It is a characteristic feature of his results that the condensation increases rapidly with increasing magnitude, so that for the limit mentioned the number of stars in the Milky Way is from 20 to 30 times that at the galactic poles.

INVESTIGATIONS OF STAR CLUSTERS.

The study of magnitudes in clusters by Mr. Shapley has led to a number of results that indicate the advantage, for certain astrophysical problems, of dealing with large stellar systems from a point outside the system. Thus we may hope eventually to obtain fairly precise information concerning the size and form of the typical clusters and the distribution of stars within them. We may determine the relative frequency of stars of different absolute luminosities and colors, as well as the relationship of color classes to magnitude and to distance from a center of attraction. Such results for clusters will be directly applicable, at least in part, to similar problems in the general galactic system.

The investigation of magnitudes and colors in the globular clusters that contain typical short-period variable stars has suggested a method of estimating, apparently with considerable accuracy, the relative distances of globular clusters. Since these objects are widely distributed over one hemisphere and relatively are very remote, the method affords an indication of the distance to which the visible stellar universe extends. Although the periods, ranges, and maximum magnitudes of the variables differ, their median magnitudes are constant for each cluster, though they vary from one system to another. Moreover, the median magnitude appears to be definitely related to the magnitudes of the brightest stars in the cluster. If the obvious assumption that differences in the median magnitudes are due entirely to distance is correct, then not only can we derive relative parallaxes as soon as the apparent magnitudes have been measured, but, with the derivation of a value for the actual luminosity of such variables, we can also obtain very accurate absolute distances for all clusters containing typical variables, as well as for the isolated variables of this class.

In collaboration with Mr. Pease, an investigation has been made of the distribution of stars in 12 globular clusters. The main outcome is the discovery that an elliptical arrangement of stars is a general characteristic of photographs of such systems. Though rarely apparent among the brighter stars, the elongation is revealed when the star counts are extended to the fainter objects and examined with respect to direction from the center. For example, from one plate of Messier 13 the number of stars for successive intervals of position angle is as shown herewith.

Sector.	No. of stars.
15°	749
45	770
75	913
105	1,008
135	1,026
165	853
195	779
225	804
255	974
285	1,011
315	963
345	763

The two maxima in the series of numbers define the axis of elongation where the stars are 30 per cent more numerous than along the minor axis. A simple interpretation of the phenomenon is that the stars in the so-called globular clusters are distributed throughout a more or less flattened spheroid, whose projection on the celestial sphere gives the observed elliptical distribution. This explanation is supported by the observed high concentration in certain clusters of blue stars and variables along the major axis, in close analogy with well-known phenomena of the galactic system.

Other cluster investigations have concerned the variable stars in Messier 3 and Messier 5. In the latter a search is being made into the colors and color variations of a group of variables with extremely short periods, discovered by Bailey at Harvard. Catalogues of magnitudes and colors have been published for Messier 11 and for four fields in the neighboring dense galactic clouds. Work on a dozen other clusters in and out of the Milky Way verifies the absence of effectual scattering of light in space, and permits a provisional estimate of the depth of the Milky Way as not less than 25,000 light-years in some directions. A study of the magnitudes of 900 stars in Messier 3 is nearing completion. In the search for very faint globular systems, the general character of a number of faint clusters has been examined. With a small photographic lens of 4 inches focal length the measurement of the integrated light of all the brighter globular clusters is under way.

VARIABLE STARS AND MISCELLANEOUS PHOTOTOMETRY.

Several miscellaneous investigations of variable stars by Mr. and Mrs. Shapley have been completed during the year, among which are the derivation of a color curve for XZ Cygni, the study of the orbits of some eclipsing binaries, and an inquiry into the magnitude and color of RU Boötis, one of the faintest of known periodic variables. Results for the last indicate a distance from the galactic plane several times greater than any heretofore found. Preliminary determinations show that the faintest variable stars in the Milky Way are red. In conjunction with Dr. van der Bilt, new light elements have been derived for W Ursæ Majoris, an eclipsing star remarkable for its very high density and short period. The analysis involved 67 minima, covering an interval of 13 years, and brought to light a small perturbation of the period. Measurement of the magnitude of the ninth satellite of Jupiter indicates that its diameter can not exceed 18 miles, if its albedo is comparable with that of the asteroids. A similar investigation of a faint asteroid, whose orbit has been computed by Mr. Nicholson and Mr. Shapley, shows it to have a diameter of approximately 3 miles; it is accordingly the smallest planetary object for which dimensions have yet been estimated. For the reductions connected with these various studies, Mr. Shapley has had the assistance of Miss Davis and, for a part of the time, that of Miss Richmond.

STELLAR SPECTROSCOPY.

The further development by Mr. Adams of the method of determining the absolute magnitudes of stars and their distances through a study of their spectra has led to some modifications of the observing program during the past year. Since each photograph of a stellar spectrum provides the means of determining the star's intrinsic brightness in addition to its radial velocity, it has seemed desirable to extend the observations to include such of the brighter stars as may be investigated in this way. Accordingly all of the stars catalogued in the *American Ephemeris* with spectral types between F0 and M have been added to the observing list.

Observations have been continued on the fainter stars with measured trigonometrical parallaxes, and this list is now nearly completed. Numerous stars of large proper motion are being investigated for luminosity and radial velocity and are proving to be objects of exceptional interest from both points of view. In addition, a considerable number of stars of small proper motion with magnitudes fainter than 6.0 has been included in the observing program. In the case of the very faint stars increasing use has been made of the 18 cm. camera. While the radial-velocity determinations obtained from such small-scale photographs are necessarily subject to considerable uncertainty, it has been found possible to secure approximate results for numerous stars which could not be obtained otherwise. For absolute-magnitude estimations these photographs are of great value.

The number of spectrograms obtained during the year is 1,095, distributed as follows:

American Ephemeris stars	475
Large proper-motion and parallax stars	268
Small proper-motion stars	287
Miscellaneous	65

Of the photographs 156 were of stars fainter than the eighth magnitude on the visual scale.

RADIAL VELOCITIES.

The radial velocities of 147 stars have been determined during the year from the measurement of three or more negatives, and one or more values are available for several hundred others. The inclusion of the brighter stars in the observing list has made it possible to compare many of the results with those obtained at other observatories, and a satisfactory degree of accordance has been found to exist. A few of the more interesting results for individual stars are as follows:

1. The spectroscopic binary Boss 46 proves to belong to the class having abnormal calcium lines. The hydrogen and helium lines show a velocity variation amounting to 485 km. with a period of 3.52 days. The calcium lines show a very slight variation or none at all.

2. Several high-velocity stars have been found. Of these the ninth-magnitude star A. G. Ber. 1866 shows a velocity of −190 km. The cluster-type variable SU Draconis has a velocity of −195 km. at maximum light.

3. Six new spectroscopic binaries have been discovered.

The most important application of the radial-velocity results has been to an investigation of the relationship between absolute magnitude and stellar motions carried out by Mr. Adams and Mr. Strömberg. For this purpose use was made of the absolute-magnitude determinations obtained spectroscopically, supplemented by luminosities derived with the aid of a modified formula connecting mean parallax and proper motion. A total of about 1,300 stars was used in the investigation. These were divided into groups situated in concentric zones about the sun within certain definite limits of parallax. A comparison of the radial motions of the stars within these groups indicates clearly an increase of velocity with decrease in absolute magnitude, independent of distance from the sun, which amounts to about 1.5 km. per unit of magnitude. A combination of the values for all the zones is shown in the accompanying table. M and V′ are the absolute magnitude and the radial velocity corrected for the solar motion.

F and G stars.			K and M stars.		
No.	M	V′	No.	M	V′
		km.			*km.*
188	0.3	11.2	125	0.5	14.6
193	1.3	13.6	164	1.4	16.6
189	3.0	14.9	124	2.5	20.6
84	5.1	17.3	74	7.0	26.9
29	6.8	21.2	13	10.0	30.0

This conclusion was further tested by the use of the velocities at right angles to the line of sight and very similar results were found. The variation with absolute magnitude is independent of the assumption of a frequency distribution of velocities in accordance with Maxwell's law, provided only that the law of distribution along the three components in space is the same. The influence of stream motion upon the results was also investigated and found to be relatively slight in the case of the stars employed. The fact that the fainter stars move more rapidly than the brighter seems, therefore, to be established definitely by this investigation.

Reference may be made to two additional products of this study of stellar magnitudes and motions. The first is the evidence that the average space velocity of the K and M type stars is about 1.0 to 1.5 km. greater than that of the F and G type stars of the same absolute magnitude. The second is the test of the accuracy of the spectroscopic determinations of parallax provided by the computation of the values derived from the stellar cross-motions; the comparison indicates close agreement for larger parallaxes and somewhat higher values than those computed in the case of the very small spectroscopic results.

A continuation and extension of this investigation is now being carried on by Mr. Strömberg. This will include a determination of the solar motion from groups of stars of different absolute magnitude, the relative effect of stream motion on stars of high and low luminosity, and a study of the velocities of stars of different intrinsic brightness with reference to the galactic plane. An interesting feature already shown by the investigation is the marked condensation of the high-luminosity stars of types F to M in the galactic plane, a result previously known to exist for the A and B stars.

SPECTROSCOPIC DETERMINATIONS OF LUMINOSITY AND PARALLAX.

The determination of the absolute magnitudes and the luminosities of stars from a study of their spectra by the method described in the report of last year has been continued by Mr. Adams and Mr. Joy, with the aid of the photographs of the stars observed for radial velocity. Magnitude determinations are now available for about 800 such stars, many of them with measured trigonometrical parallaxes. A list of 500 of these stars has been selected for publication; this includes stars for which several photographs have been obtained and a number of special interest, though with fewer observations. For 360 of these stars parallaxes have been determined in the usual way by various observers. A comparison of the results, spectroscopic *minus* directly measured values, is as follows:

Type.	No.	Systematic difference.	Mean deviation.
F0 –F8	88	+0″.006	0″.020
F9 –G7........	91	+0.007	0.023
G8 –K2........	96	–0.004	0.030
K3 –K9........	57	+0.008	0.031
Ma–Md........	28	+0.004	0.028
Total.......	360	+0.0037	0.026

There are 59 stars in the list with parallaxes measured by three or more observers. The systematic difference in the case of these stars is +0″.001. In view of this comparison it is probably not too much to state that the spectroscopic method, for all but the very largest parallaxes, is capable of yielding results of nearly the same order of accuracy as direct photographic methods with modern instruments.

Two extensions of the method have been made. The first is the use of certain additional spectral lines which has made it possible to include stars of types A8 to F5 in the investigation. The second is an attempt to derive criteria for the further subdivision of the dwarf M-type stars. Hitherto all the known stars of this type have been found to have nearly equal absolute magnitudes of about 10 to 11, but the discovery by Professor Barnard of a star with an absolute magnitude of nearly 13.5 provides an opportunity to extend the search for spectral differences to fainter stars. Several other results of this investigation may be referred to briefly.

1. Abnormal intensity of the hydrogen lines is a characteristic of the highly luminous stars of the K and M types. This is probably related to the so-called giant and dwarf division among the stars.

2. This division is very clearly shown by a comparison of the numbers of stars of each absolute magnitude. It may be traced into the stars of the G and F types of spectrum, although it is possible that the selection of the observational material may influence the results to some extent in the case of these two types.

3. A clear correspondence is shown in the behavior of the lines which vary with luminosity in stars when examined in laboratory sources. The absolute-magnitude determinations, accordingly, may be ascribed directly to a physical basis.

4. High-luminosity stars are characterized by abnormally strong enhanced lines, and fainter stars by strong low-temperature lines. Lines used for absolute-magnitude determinations are included in this more general distinction.

The measurement and reduction of the photographs of stellar spectra have been carried on by Miss Burwell, Miss Stone, Miss Brayton, and Miss Shumway. In addition to radial-velocity measurements, Miss Burwell has assisted in all of the spectroscopic determinations of absolute magnitude and parallax.

NEBULAR SPECTROSCOPY.

A few photographs were obtained by Mr. Pease with the small spectrograph at the primary focus of the 60-inch reflector. An exposure of 85 hours on the Andromeda nebula with the slit set on the minor axis of the nebula, the multiple comparison spectrum device being employed, showed no appreciable rotational velocity. The radial velocity determined by Mr. Adams from this photograph is −300 km.

A spectrogram of the star cluster Messier 5, taken under very poor conditions of definition with an exposure time of 53 hours, indicates an F-type spectrum for three stars which appear on the plate.

A photograph of the spectrum of Nova Geminorum obtained in March 1917 shows the spectrum to be essentially identical with that of the previous year. It is of the Wolf-Rayet type and appears to be relatively permanent in character.

PHYSICAL LABORATORY.

BUILDING AND INSTRUMENTS.

The congested condition of the physical laboratory has been relieved by the construction of an addition by which the floor space was approximately doubled, the new portion having an area of 31 by 44 feet. The addition contains two dark-rooms and an office, provides a more favorable installation for the interferometer spectrograph and space for a well to be excavated later for a plane-grating spectrograph of longer focus than that now in use. Three large instrument piers in the new portion are fitted with gas, water, and drain, as well as electrical connections. A large switchboard is being constructed, by means of which direct and alternating current at a variety of voltages can be supplied to all parts of the laboratory.

The auxiliary concave-grating spectrograph has been provided with a permanent mounting. Three concrete piers support the instrument and a substantial double-walled wooden housing affords efficient protection to the entire apparatus. After the adjustment of the instrument, curves giving the position of the camera and the focal setting for any wave-length were determined experimentally and found in good agreement with those calculated from the fundamental constants of the apparatus.

A new etalon embodying improvements indicated by our experience with the earlier types has been constructed, and the tests made have proved it to be highly satisfactory. The frame is entirely of steel, designed to give extreme stiffness and stability, and will accommodate plates of different thickness with separators of fused quartz up to 20 mm. in length. Six of these separators have been completed, having lengths of 2.5, 5, 7.5, 10, 15, and 20 mm. respectively. Under actual working conditions the apparatus is remarkably insensitive to thermal and mechanical disturbances—the whole order of interference is constant for a period of many weeks and the corrections necessary from time to time to insure parallelism of the plates are exceedingly minute.

The adjustment of the etalon is now carried out *in situ* with the aid of the long-focus mirror that, in actual use, projects the rings upon the slit, and after parallelism has been attained it is unnecessary to touch the instrument. Changes in thickness occurring during a day's observations amount, at a maximum, to only one part in a million.

A valuable addition to the electric equipment has been made by the purchase of a transformer of 10 kw. capacity, capable of potentials up to 120,000 volts. It is provided with a rotating contact device driven by a synchronous motor by which unidirectional discharges may be obtained; these are especially useful for high vacua.

A new arc-and-spark chamber has been built in the shop, for operating these sources either *in vacuo* or at pressures up to 5 atmospheres.

The small motor-generator set formerly used in the laboratory has been modified by exchanging the old generator giving 125 volts for a new one yielding 250 volts with a full-load output of 15 amperes. This serves admirably for operating arcs for wave-length and other precision purposes, and saves the losses formerly entailed by operating two large generators in series.

Two more adapters to permit the use of ordinary measuring machines for observing rectangular coördinates have been constructed. These are especially useful in the reduction of interferometer plates.

A small 200-line half-tone screen has been provided for use in the study of intensity distribution in spectral lines by the method of Nicholson and Merton, and a double logarithmic sector for obtaining the necessary steep intensity gradient has been constructed.

A simple glass mercury still and a new vacuum pump have been added to the laboratory equipment.

ANOMALOUS DISPERSION WITH THE ELECTRIC FURNACE.

The preliminary experiments on anomalous dispersion by Mr. King, mentioned in last year's report, showed the effectiveness of the electric furnace in producing this phenomenon, especially with vapors of the more refractory substances. A more extended investigation has been carried out during the past year, in the course of which 254 photographs were made in a study of the effect for 12 elements. In the spectra of iron, chromium, and titanium, the relative degree of anomalous dispersion was recorded for those lines which showed the effect, namely, 73 lines of iron, 47 of chromium, and 102 of titanium. This permitted a comparison of other lines with these lines of known behavior in the furnace under various conditions. Lines of special interest in the other spectra were studied in the same way.

The general conclusion was that the anomalous dispersion shown by a line is proportional to its strength in absorption, provided a proper prismatic distribution is present in the absorbing vapor. The greater prevalence of anomalous dispersion in the region of shorter wavelength appears to result from the greater absorptive power generally found for lines in this region. A point of special interest is the frequent inversion of the anomalous refractive effect for a line when the temperature is raised, indicating that the vapor prism absorbing such a line has been inverted, the stronger absorption now taking place in the cooler region above. At the same time, other lines, requiring higher temperature for their production, show anomalous dispersion of regular type. This simultaneous refraction in opposite directions for lines of different character occurred many times when two or more elements were vaporized together, and, in the case of calcium, even for lines of the same element, the low-temperature line λ 4227 showing an effect opposite to that simultaneously given by the H and K lines. The experiments have thus shown a dependence on the distribution of the radiating particles rather than on the density of the vapor as a whole. This conclusion was borne out by the observation of distinct anomalous dispersion for the band at λ 3883. On the assumption that this band is due to nitrogen alone, the results showed that the strongest absorption was given in the highly heated region, where the density of the gas was at a minimum.

GENERAL ELECTRIC-FURNACE EXPERIMENTS.

In addition to the investigation just described, 114 photographs of furnace spectra were made by Mr. King, chiefly of the spectra of iron, calcium, strontium, and barium, under various conditions of temperature, vapor-density, and surrounding atmosphere. The iron spectrum from λ 2800 to λ 6800 was photographed with the 15-foot concave grating spectrograph at temperatures of 1650°, 2000°, and 2350° C., these temperatures having been found to give the most decided differences in the spectrum. This material, with that previously obtained, will furnish a homogeneous classification of iron lines according to temperature change.

The use of the "furnace flame," produced by passing oxygen through the furnace tube during the vaporization of a metal, showed that oxidation does not decidedly modify the line spectrum of iron. The effects were more readily explained as the result of an altered distribution of the vapor. A comparison with published data on the flame spectrum of iron showed that temperature changes in the furnace can produce effects similar to those ascribed to chemical action in the flame.

The new photographs of the furnace spectra of calcium, strontium, and barium provided material as to temperature changes of important lines, and in the case of barium furnished interesting data as to line structure and the conditions which govern it. In this spectrum the lines given by the arc in air between λ 3000 and λ 3800 are in general so diffuse and unsymmetrical that no accurate measurements of wave-length can be made. Their structure in the vacuum furnace is so different from that in the arc as to present the appearance of a different spectrum. The diffuse arc lines become very sharp in the furnace and permit measures of high precision. Some, which in the arc are so hazy that no measurement has been attempted, become well defined in the furnace. Striking changes in structure also appear, a pair or triplet sometimes showing in the furnace instead of the single arc line. In case the furnace line is single, it is usually at the violet edge of the arc line, the displacements corresponding to a furnace difference of one atmosphere being very large. In the region in question the wave-lengths of 67 barium furnace lines were measured from iron standards, with a large gain both in number and accuracy over measurements possible in the arc spectrum. Tests under various conditions showed that the vacuum furnace at different temperatures gives always the same lines, but that at high temperature the stronger lines become unsymmetrical in the direction of the dissymmetry of the arc line. Increase of pressure in the furnace, however, gradually suppresses the extra components peculiar to lines in the vacuum spectrum. It appears that the structure of the arc line is due to a combination of high excitation and pressure, the former being the chief agent in causing the dissymmetry which gives rise to the wave-length differences.

The fact that the furnace lines permit of close measurement has made possible a comparison with the solar spectrum. In the case of 31 lines, the wave-lengths of barium lines in the furnace are in close agreement with faint unidentified lines of the solar spectrum. In cases where a line breaks up in the furnace into two or three components, the solar lines appear to correspond to these rather than to the line given by the arc in the air. This points to a reduced pressure and relatively weak excitation in the sun for the level at which these barium lines originate.

Analyses have been made for the spectra of two samples of rare earths suspected of containing new elements. While positive results have not been obtained, these and other experiments with furnace and arc have shown several strong lines in the ultra-violet which have not been identified in known spectra. The strongest of these agrees closely with an unidentified solar line. Extensions of stellar and nebular spectra in this region will be watched for evidences of the presence of these lines.

PRODUCTION OF SPECTRA BY CATHODE LUMINESCENCE.

The preliminary results on the excitation of metallic vapors through the bombardment by cathode rays, reported by Mr. King last year, were much extended by the experimental work of Miss Carter during the summer of 1916. Spectra of calcium and iron were obtained of sufficient richness to show what is to be expected from a source of this nature. The calcium spectrum was quite different in its features from that given by the usual sources, the various "single-line" series being strongest, followed by the series consisting of line-pairs, while the triplet series were relatively faint. The high intensity of λ 4227 was of special interest. The iron spectrum obtained showed comparatively few lines, these being lines that are strong in the furnace, arc, and spark. Stronger effects can doubtless be obtained by this method with the high-tension direct current supplied by the new transformer and rectifier. The work is again being taken up by Miss Carter, with the purpose of obtaining several of the more important spectra, so that the characteristics of intensity and structure of lines when thus excited may be definitely established.

INVESTIGATION OF THE STARK EFFECT.

The investigation of the Stark effect described in last year's report has been continued by Mr. Anderson. A plane-grating spectroscope giving intense spectra and fairly high dispersion (3 to 5 Å per mm.) was built and has been found very satisfactory. Displacements amounting to 0.01 or 0.02 Å can readily be detected, and the brightness is such that the exposure time need rarely exceed 30 minutes.

A vacuum chamber suitable for use with metals having high melting-points presented some experimental difficulties, but one was finally devised which has worked well, and during the year some 100 or more spectrograms of iron, chromium, nickel, vanadium, titanium, and manganese have been secured. A general survey of the electric effect for chromium, nickel, and iron has been made with the following results:

1. The majority of the arc and spark lines shows no appreciable electric displacement or decomposition.
2. A few hazy arc lines of Cr and Ni are affected by the electric field, showing either displacement or decomposition.
3. The affected lines are relatively very intense in the field, especially after the cathode has been used for a few hours without coming in contact with air at pressures above a few millimeters.
4. In all, 74 affected lines ascribed to Cr, 8 to Fe, and about 12 to Ni have been recorded.
5. The relative intensity of all the lines in the electric field differs from that of the arc, spark, or furnace, and will no doubt be an interesting subject for future work.
6. A few of the affected Cr lines appear in the sun, and their study will make possible a determination of the upper limit of intensity of possible electric fields existing at this level in the solar atmosphere. Preliminary measures of these lines in sun-spots show no appreciable electric effect.

DEVELOPMENT OF THE PFUND ARC FOR STANDARD PURPOSES.

An extensive investigation by Mr. Babcock and Mr. St. John has had for its purpose the development of an improved source of secondary standards of wave-length, free from the disturbing influences of pole effect. The interference apparatus recently installed has proved of great service in this investigation. It possesses the important advantages found in complete achromatism of the mirror system and in comparative freedom from temperature disturbances resulting from the use of fused-quartz plates and separators in the etalons. By the use of large-scale interference rings and increased auxiliary dispersion an anticipated gain in accuracy has been reached. The evidence collected with this apparatus and with the 30-foot plane-grating spectrograph, confirmed by independent observations of sun-arc displacements with the instruments on Mount Wilson, has established the presence of pole effect in the international arc, the source adopted for the production of secondary standards of wave-length. Even in the center of this arc, displacements amounting on the average to 0.006 Å are found for unstable lines. It has also been shown that the center of the 6 mm. 6-ampere Pfund arc, formerly thought to be free from pole effect, is somewhat affected. Modified specifications have been developed, however, by means of which the uncertainties due to pole effect are eliminated. As a result, the unstable lines of iron may now safely be employed in astrophysical investigations far more widely than heretofore. Within the limits of observational error, stable lines have been found to have the same wave-lengths in all the different forms of arcs which we have tested.

For the unstable lines the need of a definition of the fundamental wave-length has become evident. Provisionally it is defined as the wave-length free from displacements due to conditions in the arc itself, which are associated with proximity to the poles but extended in range by increase of current. Evidence that a fundamental state may be attained is furnished by three lines of investigation: change of arc length, of current strength, and of constituents of the negative pole. When no further variation in wave-length accompanies a change of any one of the variables, the other two being constant, it is assumed that the fundamental condition has been reached.

A study of the widths of iron lines in various sources has shown that at atmospheric pressure the Pfund arc with negative pole of carbon yields the narrowest lines, especially when operated at a length of 10 to 15 mm., with a current of 4 or 5 amperes. A close rival is found in the center of the 5-ampere 12 mm. Pfund arc, which is the source recommended by Mr. St. John and Mr. Babcock for the production of secondary standards of wave-length. The center of the international arc is far inferior in this regard, and many lines in it are widened to such an extent as to be wholly unsuited to interference measurements.

As a source of reference standards for the comparison of the relative intensities of spectral lines, the center of the 5-ampere 12 mm. Pfund arc is found to be superior to the other forms mentioned above. This is due to the fact that the unstable lines are well developed in it, but still have moderate intensity gradients from the center of the arc to the poles.

SECONDARY STANDARDS OF WAVE-LENGTH.

For reasons set forth above, namely, the need of fundamental wave-lengths for unstable lines and increased reproducibility for all classes of lines, it became necessary to determine secondary standards in the center of the 5-ampere 12 mm. Pfund arc. This has required a repetition of part of the work noted in the last annual report, although the majority of the measurements of early plates can still be used. Determination of wave-lengths by the interference method were discontinued until the completion of the study of sources, but the investigation is now well advanced under improved observing conditions; 37 new photographs, all from a source free from pole effect, are now being reduced. On these plates 506 iron lines between the limits λ 3370 and λ 5085 have been determined in terms of selected lines from the published list of secondary standards. The increased sharpness in the iron lines yielded by the source adopted for our work makes possible the use of higher orders of interference than have hitherto been employed, and this involves a considerable increase in the amount of work, not only on account of the greater number of lines suitable for measurement, but also because of the additional plates which must be taken. Many of the poorest lines in the iron spectrum can be measured with high precision when free from pole effect. The methods of reduction have been simplified as far as is consistent with accuracy. Aside from the adjustment of the etalon, no observations are required except the measurement of two or three diameters for each line.

A study of the relative values of the wave-lengths of the stable secondary standards has led to the use of these instead of the red cadmium line. There is no doubt that the published wave-lengths of the stable lines are accurately corrected for phase change and nothing is to be gained by redetermining them, while the saving of labor is very great. We are not precluded from introducing our own values of the relative wave-lengths when these differ by small amounts from those published.

In the measurement and reduction of the numerous photographs required for the interferometer investigations, much assistance has been given by Miss Margherita Burns, who has devoted all her time to the work, and, during the latter part of the year, by Miss Brayton.

WAVE-LENGTHS OF IODINE ABSORPTION LINES.

In addition to the determination of wave-lengths of iron lines by the interference method, 20 absorption lines of iodine have also been measured by Mr. Babcock with high orders of interference in terms of selected iron standards. The iodine lines are among those which lie superposed upon iron lines and are valuable as reference marks in the spectrum.

WAVE-LENGTHS OF SPARK LINES.

A few interferometer plates have been reduced by Mr. Babcock for the purpose of comparing wave-lengths of iron lines in arc and spark. Lines of groups a and b are found to have the same wave-length in both sources, while those of group c_4 have slightly greater wave-lengths in the spark. Groups c_5 and d are shifted to the red about 0.007 Å in the spark and group e to the violet about 0.008 Å.

PRESSURE EFFECT FOR IRON.

A redetermination of the pressure effect for iron has been undertaken by Mr. Babcock, in view of the discovery that pole effect has played a part in most previous work on this subject. Observations are made *in vacuo*, at atmospheric pressure, and at a pressure of two atmospheres, with precautions to avoid the introduction of pole effect. The interference apparatus, admirably adapted for this work, will be mented by the 30-foot spectrograph. Although the data at hand are meager, it may be said that the values for the stable lines of iron are in good agreement with former determinations, but for the sensitive lines the displacements appear to be somewhat reduced.

INTENSITY DISTRIBUTION IN WIDE IRON LINES.

Preliminary work on this problem has been undertaken by Mr. Babcock by the method of Nicholson and Merton in conjunction with the 30-foot spectrograph. The photographs taken thus far serve to illustrate the technique of the process, but are not definitive. It is planned to adapt the apparatus for use in conjunction with the interference method on account of the high dispersion thus made available.

SENSIBILITY OF FOUCAULT KNIFE-EDGE TEST FOR OPTICAL SURFACES.

In an interferometer of the Fabry and Perot type, residual errors in planeness of the optical surfaces accumulate with the multiple reflections and set a definitive limit to the resolving power obtainable. Further improvements in this type of instrument thus depend largely on increase in accuracy of the surfaces and this in turn requires higher sensibility in the methods of testing. An investigation was undertaken by Mr. Anderson and Mr. Babcock to find how far the Foucault test could be relied on for surfaces of any size, with the result that it appears possible to detect a general curvature amounting to only 1/75 of a wave-length, without regard to the absolute size of the surface. The investigation was marked by unusual precautions to guard against the introduction of bias on the part of the observers.

CONSTRUCTION DIVISION.

DRAFTING AND DESIGN.

A large proportion of the work of the drafting department has been related to the 100-inch telescope and its accessories. Difficulties connected with the operation of the observing platform led to a re-design of this important adjunct to the instrument, and the progress of the erection has necessitated occasional modifications of some of the auxiliary apparatus. The spectrograph for use at the Cassegrain focus has been designed, together with one of the double-slide plate holders. The detail drawings have been completed for the right ascension and declination telescope controls, the two long-focus cages, and the Newtonian cage, with their mirror supports, and many other portions of the mounting and attachments.

In addition to the 100-inch telescope work, drawings for instruments include the following:

Comparator for measurement of direct photographs 3.5 inches square.
Diamond polishing machine.
Pressure arc.
Pitch micrometer, 6-inch inside and outside micrometers.

The drafting department has also made the drawings for extensions to the Monastery and the Pasadena Laboratory. Mr. Pease has continued in charge of this department and Mr. Nicholson has acted as chief draftsman.

THE OPTICAL SHOP.

The completion of the two convex mirrors used in conjunction with the 100-inch mirror in the Cassegrain and coudé combinations occupied the first part of the year in the optical shop, which has remained under the charge of Mr. Ritchey. These mirrors, after being ground and polished to a spherical form, were hyperbolized with the aid of the large mirror. The 60-inch plane mirror was utilized to reflect the parallel beam, and, by a slight rotation of this mirror, the field at the equivalent focus of the system could be examined at any desired distance from the axis.

As soon as the work of figuring the convex mirrors had been finished, there was no further necessity for retaining the 100-inch mirror in Pasadena. Arrangements were accordingly made for its transportation to Mount Wilson, and this operation was carried out early in July. The mirror was crated in a strong box lined with building paper and supported on its edge by a heavy frame-work bolted to the bed of the motor truck. To reduce the amount of vibration, numerous springs were inserted between the box and the frame-work. The top of the mirror box when placed on the truck was about 14 feet from the ground and its weight, including the support, was 7.5 tons. The trip up the mountain was made without incident, the specially geared truck performing its work without difficulty.

The two large oval plane mirrors to be used in the 100-inch telescope have been shaped and fine-ground. One of these, the Newtonian flat, is exceptionally thick and its edge has been beveled in order to reduce the amount of intercepted light. Two mirrors 9 inches in diameter have been completed for use in the coudé form of the telescope when only the center of the field is employed. For spectroscopic work this will obviate the necessity of resilvering the large oval plane at frequent intervals.

Additional work in the optical shop has included two 12-inch plane mirrors for use in the Snow telescope spectrograph, several speculum metal planes for diffraction gratings, and six small mirrors for special experiments.

INSTRUMENT SHOP.

The work of the instrument shop, as in previous years, has been under the direction of Mr. Ayers, foreman, with Mr. Jacomini as chief instrument maker. Much difficulty has been encountered in securing a suitable end-thrust bearing for the ruling-machine, the artificial rubies used for this purpose frequently breaking down, owing to minute flaws and bubbles near the surface. Recent experiments, however, give promise of a solution of this problem. Mr. Jacomini has also given much time to questions connected with the erection of the 100-inch telescope; the cutting of the large driving worm-wheel has been carried out under his supervision.

Over 40 per cent of the work of the instrument shop has been connected with the 100-inch telescope, the construction of the three additional mirror cages being the largest single item. Among other important undertakings, reference may be made to the following: attachments to Snow cœlostat and to 30-foot spectrograph for the Snow telescope, auxiliary apparatus for the 10-inch refractor, a stellar comparator, pressure arc, vacuum pump, diamond polishing-machine, dividing engine, and two small grinding and polishing machines for optical work. Since July 1 almost the entire time of the instrument shop has been given to the construction of precision micrometers for the use of the Government.

ONE-HUNDRED-INCH TELESCOPE.

The completion of the building and dome for the 100-inch telescope in the summer of 1916 left the erection of the mounting as the chief outstanding problem in connection with the instrument. This has been in progress throughout the year under the direction of Mr. Sherburne. For reasons given in the last report, it was impracticable to assemble completely the mounting at the Fore River Works. As a result it has been necessary to proceed rather slowly with the erection and to fit and drill many of the members. Good progress has been made, however. The pedestals, mercury tanks and floats, the polar axis, and the tube are in place, and the rotation of the instrument on its bearings has been tested. The right ascension and declination slow and fast motions have been completed and attached, the large driving worm-wheel has been cut and partially ground, the mirror cell has been fitted, and the support system installed. The Cassegrain cage has been riveted together and ground true, and the mirror elevator has been assembled and tested. Although the work of erection must necessarily be somewhat delayed by the pressure of work in the Pasadena instrument shop, we hope to have the telescope ready for tests during the autumn.

The difficult and complicated task of wiring the instrument and dome, and the construction of the switchboards and much control apparatus of special design, has been in charge of Mr. Dowd, our engineer.

OTHER CONSTRUCTION WORK.

Two important pieces of construction work have been carried on under the supervision of Mr. Jones. The first was the addition to the Pasadena physical laboratory, completed during the winter. The crowded condition of the building and the necessity of providing space for additional apparatus have been recognized for several years. Fortunately the original building lent itself admirably to an extension and the floor space has thus been nearly doubled.

The approaching completion of the 100-inch telescope and the necessity of providing for additional observers on Mount Wilson has led to the construction of a two-story concrete building adjacent to the Monastery. The building contains eight rooms and, so far as possible, will be devoted to the night observers, those engaged in solar work living in the Monastery itself.

Much general repair work has been done and many improvements to the instruments and buildings have been carried out. Several retaining walls have been built on Mount Wilson to prevent washing of some of the steeper slopes by the winter rains.

AN ELECTRIC-POWER TRANSMISSION-LINE TO MOUNT WILSON.

In the spring the Southern California Edison Company submitted a proposal to extend a transmission line up Mount Wilson for the supply of electric power to the Observatory and the hotel company. Terms of agreement were soon drawn up and construction work was begun in July. The line is now well advanced and should be in operation during the autumn. Since all of the electric motors used in connection with the instruments operate on direct current, a large motor-generator set has been installed in the power house to transform the alternating current into direct.

An abundance of electric power on the mountain will be of great value to the Observatory, not only for the operation of the instruments, but also for special investigations which involve the use of a powerful spark or an electric furnace. Probably it will also be utilized to some extent for domestic purposes at the Monastery. The present power plant will be maintained for use in emergencies and when the transmission line is out of service. The spectroheliograph and such other instruments as require a very constant current will be operated from the storage battery, this being charged by the motor-generator set.

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ORGANIZATION OF THE MOUNT WILSON SOLAR OBSERVATORY, SEPTEMBER 1, 1916, TO AUGUST 31, 1917.

GEORGE E. HALE, *Director.*
WALTER S. ADAMS, *Assistant Director.*

RESEARCH DIVISION.

Solar Physics: George E. Hale, in charge; Charles E. St. John, Ferdinand Ellerman, Adriaan van Maanen, Alfred H. Joy, Seth B. Nicholson.

Stellar Spectroscopy: Walter S. Adams, in charge; Alfred H. Joy, Gustaf Strömberg, Francis G. Pease.

Stellar Photometry: Frederick H. Seares, in charge; Harlow Shapley.

Nebular Photography: G. W. Ritchey; Francis G. Pease.

Stellar Parallax: Adriaan van Maanen.

Physical Laboratory: Arthur S. King, in charge; J. A. Anderson; Harold D. Babcock.

RESEARCH ASSOCIATE.

J. C. Kapteyn, University of Groningen.

COMPUTING DIVISION.

Frederick H. Seares, superintendent; Ada M. Brayton, Carolyn O. Burns, Margherita O. Burns, Cora G. Burwell, Helen Davis, Mary C. Joyner, Addie L. Miller, Myrtle L. Richmond, Bertha M. Shumway, Ruth A. Stone, Louise Ware, Lucile Winn, Coral Wolfe, computers; Elizabeth Connor, librarian.

OFFICE AND DESIGN.

Francis G. Pease, instrument design; E. C. Nichols, H. O. Nicholls, Roy Barlow, draftsmen; Deforest S. Mulvin, bookkeeper; F. Louise Gianetti, stenographer; Beulah Thompson, telephone operator.

INSTRUMENT CONSTRUCTION.

Optical Shop: G. W. Ritchey, chief optician; W. L. Kinney, optician; James Dalton, assistant optician.

Instrument Shop: Clement Jacomini, chief instrument maker; Alden F. Ayers, foreman; C. D. Shumway, machinist; James Chapman, pattern maker; Elmer Prall, Warren Howell, machinists; Ernest Keil, instrument maker; Caleb Moore, cabinet maker; Albert McIntire, Max L. Derr, H. B. Terbeck, M. C. Hurlbutt, W. B. Wuest, machinists; Fred Scherff, Oscar Swanson, Fred Hensen, apprentice machinists; J. T. Wagner, helper.

OPERATION AND ERECTION.

George D. Jones, superintendent of transportation and erection; Gardner Sherburne, in charge 100-inch telescope erection; Merritt C. Dowd, engineer; Sam Jones, assistant engineer; W. P. Hoge, night assistant; R. R. Campbell, day assistant; D. C. Johnson, steward; J. Fred Burt, Kenneth Pitt, B. H. Terbeck, janitors; Thomas A. Nelson, truck driver.

(Several of the individuals whose names are listed above have been associated with the Observatory only a part of the year.)